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Space Research

Office of Biological and Physical Research

Winter 2003, Vol. 3 No. 1

Inspiring the Next Generation of Explorers

Profile: Roger Crouch

National Aeronautics and Space Administration

Letter From the Associate Administrator

The journey into space does not begin at the launch pad; it begins at the classroom door. NASA's mission, "to understand and protect our home planet, to explore the universe and search for life, and to inspire the next generation of explorers … as only NASA can," depends on educated, motivated people. These people have the ingenuity to invent new tools, the passion to solve problems, and the courage to ask the difficult questions.

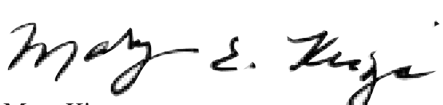
NASA has always been committed to encouraging curiosity and exploration as well as sharing its findings with educators and students at all levels. And what student doesn't jump at the chance to ask about what an astronaut's life is like in microgravity ("Do astronauts get taller in space without the compression of gravity?" "Do astronauts take showers in space like people on Earth do?"). Such questions necessarily have ties to science. To bring more structure and comprehensiveness to the agency's efforts to provide space science–related tools for imaginative and engaging lessons in science, technology, engineering, and math, NASA has established the Education Enterprise. This enterprise is dedicated to ensuring that education is an integral component of every major NASA research and development mission. Many of those missions are based in the Office of Biological and Physical Research (OBPR), where energy and resources already support education.

As you'll read in this issue's feature, "Inspiring the Next Generations to Take the Journey," OBPR's educational outreach efforts, which appeal to a wide range of interests and levels, are designed to be authentic (based on current space research); relevant to a standards-based curriculum; and conducive to linking educators and students with researchers, their science, data, and research facilities. These efforts are being revised, where needed, to help meet new priorities for OBPR's effort in support of the Education Enterprise. These priorities are to

- Increase the number of students reached and the interactivity of student opportunities;
- Enable educators to enhance science, technology, engineering, and mathematics instruction with space research concepts;
- Increase OBPR's reach to more nontraditional and underrepresented students and educators; and
- Strengthen OBPR's higher education programs.

I believe that educational outreach is integral to OBPR research programs and wholeheartedly support efforts that are already in place as well as those being developed. For example, at Texas A&M University in College Station, middle school teachers study the effects of microgravity on the body's cardiovascular, nervous, musculoskeletal, and immune systems. In the "Science in a Box" project, high school students learn how astronauts conduct some of the research on the International Space Station by building a replica glovebox (a transparent compartment about the size of a medium microwave oven that has glove inserts for manipulating the contents) and then completing activities in science, math, and technology using the box. Minority undergraduate students attend NASA's Spaceflight and Life Sciences Training Program at Kennedy Space Center, Cape Canaveral, Florida, to study ecology, controlled biology systems, or flight engineering and management. Undergraduate and graduate students can take bioastronautics classes at University of Colorado (CU), Boulder, and work on real NASA projects as part of an educational outreach program at CU run by BioServe Space Technologies (one of 15 NASA research partnership centers administered through OBPR's Space Product Development Division).

As OBPR uses these programs and dozens of others in our work with the Education Enterprise, we will help create a strategy that supports national and state education agendas. And in doing so, we also will accomplish our mission to inspire the next generation of explorers, in support of NASA's overarching vision.



Mary Kicza
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On the cover:
Physicist and former astronaut Roger Crouch poses with students at the opening of the NASA @ your library exhibit (see page 16 in this issue) at the Enoch Pratt Free Library in Baltimore, Maryland. Through this and many other educational outreach programs, the Office of Biological and Physical Research endeavors to inspire the next generations of scientists and explorers to continue NASA's journey into the future. credit: NASA

Space Research is published quarterly by the **Marshall Space Flight Center (MSFC)** in conjunction with **Hampton University**, **Pace and Waite Inc.**, and **Cherokee Nation Industries Inc.** Address comments and newsletter requests to Coordinator, Microgravity Research Program Office, Bldg. 4201, SD45, Marshall Space Flight Center, AL 35812. Send mailing list additions and updates to *Teresa.Jones@hamptonu.edu*. Please provide your name, title, address, and phone number.

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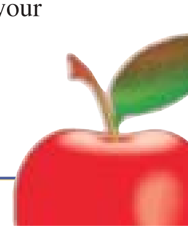


Grunsfeld Succeeds Lucid as NASA Chief Scientist

credit: NASA

Astronaut, astronomer, and astrophysicist John Grunsfeld replaced Shannon Lucid as NASA's chief scientist in September 2003. In his new role, this veteran of four space shuttle flights (including two servicing missions to the Hubble Space Telescope [HST]) will ensure the continued scientific merit of NASA's programs, including space-based science objectives.

Grunsfeld was selected as an astronaut in 1992 and made his first flight in 1995 aboard Space Shuttle *Endeavour* on STS-67. He also flew aboard *Atlantis* on STS-81 in 1997, which included a 10-day mission to Russian Space Station *Mir*. In 1999 and 2002 on space shuttle flights STS-103 and STS-109, respectively, he took part in five successful spacewalks to upgrade the HST.

Grunsfeld received a bachelor's degree in physics from the Massachusetts Institute of Technology (Cambridge) in 1980 and master's and doctorate degrees in physics from the University of Chicago (Illinois) in 1984 and 1988, respectively. His research interests include X-ray and gamma-ray astronomy, high-energy cosmic ray studies, and the development of new detectors and instrumentation. He also studies binary pulsars and energetic X-ray and gamma-ray sources using the NASA Compton Gamma Ray Observatory, X-ray astronomy satellites, radio telescopes, and optical telescopes, including the HST.

Grunsfeld was the W. D. Grainger Postdoctoral Fellow in Experimental Physics at the University of Chicago from 1988 to 1989 and a senior research fellow at the California Institute of Technology, Pasadena, from 1989 to 1992. He was awarded the NASA Distinguished Service Medal in 2003. He also received NASA Space Flight Medals in 1995, 1997, 1998, and 2000 and earned the agency's Exceptional Service Medal in 1997, 1998, and 2000.

Lucid, a Congressional Space Medal of Honor winner, had been selected as chief scientist in February 2002 (see *Space Research*, June 2003, p. 4). Her main objective as chief scientist was to develop a comprehensive plan for prioritizing research on the International Space Station. She also updated NASA's science policy, which last had been updated in 1996, to stipulate that science grants will be peer reviewed and that NASA scientists must compete for research funding.

Schowengerdt Moves from Rail Commerce to Space Commerce

credit: NASA

Frank Schowengerdt was recently selected as director of the Office of Biological and Physical Research's (OBPR's) Space Product Development (SPD) Division. Previously, Schowengerdt was director of the Center for Commercial Applications of Combustion in Space (CCACS), a NASA research partnership center based at the Colorado School of Mines in Golden. He retired from the center in 2003, after 7 years of service, to become the SPD director.

Schowengerdt's long and eclectic career began as a freight claim agent with the Missouri Pacific Railroad from 1954 to 1956. He served with the U.S. Navy in the field of aviation electronics, then earned bachelor's, master's, and doctorate degrees in physics from the University of Missouri at Rolla.

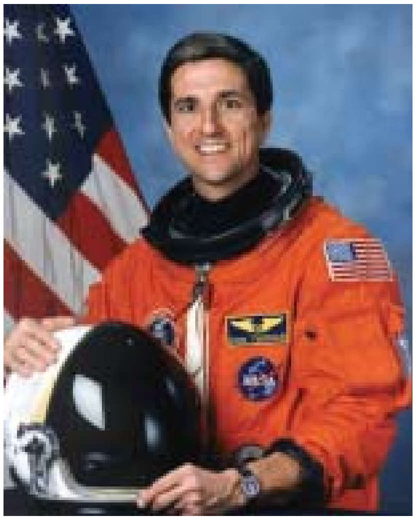
On receiving his doctorate in 1969, Schowengerdt started his teaching career. Within a few years, he was a tenured professor of physics at the Colorado School of Mines, where he later became vice president for academic affairs and dean of faculty (1990–1995). From 1985 to 1990, he was also chairman of the board of the Colorado Advanced Materials Institute, and from 1987 to 1988, he participated in the Distinguished Visiting Scientist Program at the California Institute of Technology's Jet Propulsion Laboratory in Pasadena.

While maintaining his position as a physics professor, in 1996 Schowengerdt became director of the CCACS, the Colorado School of Mines' first involvement in space endeavors. One of the center's research payloads in fire suppression using fine water droplets, called Water Mist, flew on STS-107. The crew of Space Shuttle *Columbia* downlinked a legacy of useful research results that may contribute to the safety of future crews. Another major research payload is in development, the Space-DRUMS containerless processing facility, which may be used to develop advanced ceramic materials for applications in biotechnology and biomedicine, such as improved hip and knee implants. As the new director of the SPD Division, Schowengerdt looks forward to advancing commercial space research initiatives while supporting OBPR's key research goals.

Readership Survey Update

The *Space Research* readership survey was extended, and results of the survey are still being tabulated. A summary of the results will be printed in the Spring issue of the magazine.

Donald Thomas Selected as International Space Station Program Scientist



credit: NASA

In August 2003, astronaut and materials science researcher Donald Thomas was named NASA's new International Space Station (ISS) program scientist, replacing Neal Pellis. As ISS program scientist, Thomas is based in Houston, Texas, at Johnson Space Center (JSC) and works with principal investigators and the ISS program office to ensure that scientific and engineering requirements for research on the ISS are clearly communicated among all participants. He also serves as the science spokesperson for the ISS program to the scientific and international research communities as well as the general public.

In 1988, Thomas joined JSC as a materials engineer. His work involved lifetime projections of advanced composite materials for use on a space station. He was also a principal investigator for the Microgravity Disturbances Experiment, a middeck crystal growth experiment that flew on STS-32 in January 1990 to investigate the effects of disturbances caused by the space shuttle and its crew on crystal growth in a microgravity environment.

Thomas was selected for the astronaut corps in January 1990 and became an astronaut in July 1991. He was a mission specialist on STS-65 in July 1994, STS-70 in July 1995, STS-83 in April 1997, and STS-94 in July 1997; three of these flights were Spacelab missions. On both the second International Microgravity Laboratory mission and the Microgravity Science Laboratory mission (and its reflight), Thomas focused on life sciences, materials, and combustion research.

Thomas received a bachelor's degree in physics from Case Western Reserve University, Cleveland, Ohio, in 1977, and master's and doctorate degrees in materials science from Cornell University, Ithaca, New York, in 1980 and 1982, respectively. His doctoral dissertation evaluated the effects of crystalline defects and sample purity on the superconducting properties of the element niobium.

NASA has conferred several awards on Thomas, including the NASA Sustained Superior Performance Award, four NASA Group Achievement Awards, four NASA Space Flight Medals, two NASA Exceptional Service Medals, and the NASA Distinguished Service Medal.

Pellis, who retained his positions as chief of the Biological Systems Office and manager of the Cellular Biotechnology Program at JSC when he was appointed as the ISS program scientist in May 2002, became associate director of the JSC Biological Sciences and Applications Office in August 2003.

Introducing the International Space Station Expedition 8 Science Officer

credit: NASA

Expedition 8 Commander and International Space Station (ISS) Science Officer Michael Foale arrived on board the ISS in October 2003. This expedition marks Foale's sixth spaceflight and his second long-term spaceflight mission. As ISS science officer, Foale works with the research community to help each experiment achieve maximum return on research investment.

Foale is a veteran of five space shuttle flights: STS-45 (1992), STS-56 (1993), STS-63 (1995), STS-84 (1997), and STS-103 (1999). The STS-84 flight transported Foale to Russian Space Station *Mir*, where he stayed for more than 4 months. He initially spent his time conducting experiments, then helped repair the space station after it collided with a Progress supply ship and depressurized.

Foale received his Bachelor of Arts degree in physics with First Class Honours from the University of Cambridge, Queens' College, England, U.K., in 1978. He went on to earn a doctorate in laboratory astrophysics from Queens' College in 1982. In June 1983, he joined Johnson Space Center (JSC), Houston, Texas, in the payload operations area of the Mission Operations Directorate. He was responsible for payload operations on several space shuttle missions before being selected as an astronaut candidate in June 1987. Before his first space shuttle flight, Foale helped to test and verify space shuttle flight software and developed crew rescue and integrated operations for the ISS.

Foale's Expedition 8 crewmate is cosmonaut Alexander Kaleri, the ISS flight engineer. The crew was joined in the Soyuz flight to the ISS by European Space Agency astronaut Pedro Duque from Spain. Duque remained aboard the ISS for 8 days and then returned to Earth with the Expedition 7 crew, Edward Lu and Yuri Malenchenko.

Inspiring the Next Generations

"NASA's missions once inspired a generation to explore the stars and race for the Moon. While our missions and points of destinations have changed, the same challenges remain very much a part of our future. We accept our responsibility to inspire a new generation of explorers and we will succeed in ways that only NASA can."
— Sean O'Keefe, NASA Administrator

NASA has a new vision: to improve life here, to extend life there, and to find life beyond. The Office of Biological and Physical Research (OBPR) contributes to NASA's realization of this vision through commitment to five research organizing questions. The OBPR's Educational Outreach Program is dedicated to addressing the fifth question: How can NASA best educate and inspire the next generations to take the journey?

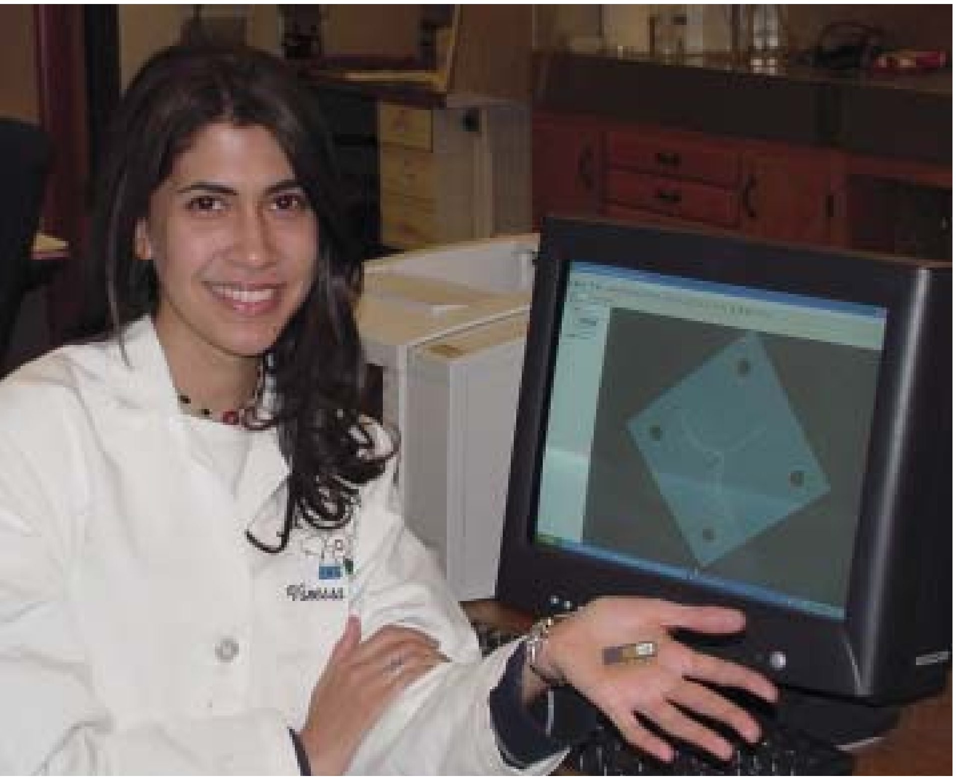
How *can* NASA *educate* and *inspire* a new generation of explorers? How can NASA *engage* the public in exploration and discovery?

These great questions also hold the answers! Questions initiate pathways that generate potential solutions. Those who navigate these pathways will be the leaders of the next generation of explorers.

People of all ages are curious about the impacts of space research and how it may affect them today or shape their tomorrows. Questions frequently asked of OBPR Educational Outreach include, "What happens to the human body in space?," "What new things can be learned from research in microgravity?," and "How does space research make life better on Earth?"

Five research organizing questions

- How can we assure survival of humans traveling far from Earth?
- How does life respond to gravity and space environments?
- What new opportunities can research bring to expand understanding of laws of nature and enrich life on Earth?
- What technology must we create to enable the next explorers to go beyond where we have been?
- How can we educate and inspire the next generations to take the journey?



Doctoral student Vanessa Aponte shows a micron-scale device that she is using to develop a real-time biological sensor for monitoring the status of an astronaut's immune system. Aponte is participating in a two-pronged program that offers courses in bioastronautics in the aerospace engineering sciences department at the University of Colorado, Boulder, and opportunities to conduct research at BioServe Space Technologies, a NASA research partnership center located on campus.

credit: BioServe Space Technologies

OBPR is in an exceptional position to respond to the recognition that space research is a powerful, motivational learning tool. The OBPR Educational Outreach Program brings activities to learners that engage them in ground-based and spaceflight research. Participants learn why and how research is conducted in some of the most unique laboratories in the world by leading scientists and engineers. Communication from the space shuttle and the International Space Station (ISS) brings the laboratory of space research into classrooms and homes around the world.

All OBPR educational programs and activities are based on three core values, have direct connections to the five research organizing questions, and are directed to four primary audiences. OBPR's educational activities bring the current science of space exploration and discovery to learners of all ages by application of the three core values — authentic, linked, and relevant. Activities provide learning experiences that use authentic research, its tools, and its processes. Direct links to NASA researchers, their science, NASA facilities, and real data are established through various delivery modes. Care is taken to illustrate how these activities are relevant to standards-based curricula.

Alignment with the core values enables learners to gain an understanding of science, an appreciation for the scientific way of thinking, and insight into what the life of a scientist may be like. These activities simulate authentic research conditions and promote new perspectives and application of science concepts in science, math, chemistry, human physiology, engineering, technology, and physics courses. Experiencing space

to Take the Journey

credit: NASA

As part of the Spaceflight and Life Sciences Training Program, student Michael Liga investigated the effects of ethanol on the growth and development of radishes. Being able to grow crops in microgravity during long-term missions will help reduce a crew's dependence on limited food supplies. Liga is an agricultural and biosystems engineering student at the University of Arizona, Tucson.

research may influence a science career choice or prompt a desire to increase personal scientific knowledge.

Direct connections to OBPR research questions

OBPR's research plan features five research organizing questions. The content of these questions holds a substantial richness for use in learning environments. Learners have consistently been attracted to the investigations of life and microgravity sciences. As students probe for answers, they will become acquainted with what it takes to be a scientist or engineer — from the scientific way of thinking to the investigation protocols required.

Primary audience and priorities

The OBPR Educational Outreach Program has identified four primary audiences — students, educators, underrepresented and nontraditional groups, and the higher education community — and defined priority objectives that relate to these audiences. The four priorities are to

- Engage students: increase numbers of students reached and interactivity of student opportunities;
- Empower educators: enable educators to enhance science, technology, engineering, and mathematics instruction with space research concepts;
- Expand audiences: increase our reach to nontraditional and underrepresented students and educators; and
- Enhance higher education reach: review, improve, and strengthen the OBPR higher education programs.

By bringing space research to education, OBPR seeks to provide the authentic linkages that inspire; the relevant, supplemental materials that educate; and the portion of the pipeline that results in a cadre of tomorrow's explorers.

Sample programs

Keeping with programmatic priorities, the OBPR Educational Outreach Program strives to create innovative activities that resonate with the core values and reflect scientific content linked to the organizing questions. It is a daunting task. But it is one that the OBPR accepts with enthusiasm. Highlighted below are examples of successful OBPR educational activities that meet these objectives.

Better health from space to Earth

Teaching kids about the importance of nutrition and exercise is a lesson that will keep them healthy for a lifetime. Better Health from Space to Earth, a new program in the NASA CONNECT education series, will get students thinking about fitness by showing them the health challenges that face astronauts who live in a microgravity environment for extended periods.

The three-component program for sixth through eighth graders includes a television broadcast, a teacher's guide that describes a hands-on activity, and an interactive web activity. Through this program, students learn to measure heart rates, read nutrition labels, and evaluate their own diets using the U.S. Food and Drug Administration's food pyramid. The first television broadcast was scheduled for November 2003.

Science in a box

Conducting experiments in microgravity requires special equipment and innovative thinking. The Science in a Box program helps high school students build a replica of an experiment facility used on the International Space Station (ISS) and encourages them to consider how a microgravity environment might affect experiments.

Science in a Box includes instructions for building a glovebox, which is a small sealed box with glove inserts for astronauts to manipulate experiments when contamination of or by experiment samples is a concern. A companion guide describes related activities in science, math, and technology that can be performed in the completed box. The guide also gives background about the glovebox on the ISS and some experiments that have been conducted in it.

A trip to space for Biology 101

College educators looking for a new approach to teaching the basics of biology may find just the ticket

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Research Update: Bioastronautics Research

Pumping Iron in Microgravity

Spaceflight weakens astronauts, but new exercise regimens promise to change that — and deliver important benefits on Earth as well.

Video feeds from the International Space Station (ISS) invariably show crewmembers exercising in the background. Exercise is serious business on the ISS because microgravity causes skeletal muscles to lose power and stamina. Workouts help astronauts fight back.

Yet despite rigorous workouts, astronauts return to Earth shockingly weaker than when they left. Only 11 days in microgravity may atrophy (shrink) muscle fibers as much as 30 percent and cause soreness as damaged muscles tear while readjusting to Earth's gravity.

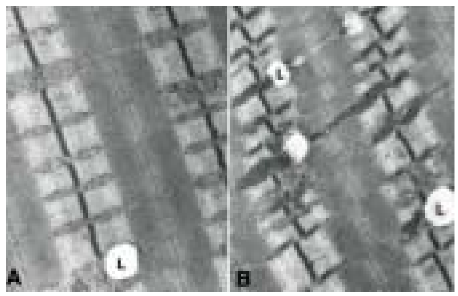
Earthly implications

Fortunately, muscles recover rapidly after weeks in microgravity. But what might happen during a years-long mission like a trip to Mars? How long would muscles atrophy during spaceflight, and what levels of muscle strength would the astronauts have when equilibrium is reached? Could more vigorous aerobic workouts prevent wasting, or would other types of exercise be more effective? Such questions intrigue Robert H. Fitts, professor of biology at Marquette University in Milwaukee, Wisconsin. He has been examining astronauts' muscle tissue before and after ISS missions to project how longer spaceflights would answer these and other questions.

Fitts, an expert on exercise physiology and a serious runner, says that his ISS research will help develop workouts for astronauts to minimize or even prevent atrophy. Any success would also deliver benefits on Earth, where similar exercises could help the elderly stay strong and speed the rehabilitation of certain patients after lengthy illnesses.

Pumping iron

Muscle atrophy involves many subtle chemical as well as physical interactions,



credit: Danny Riley and James Bain, Medical College of Wisconsin

The presence or absence of gravity affects skeletal muscle tissues, as shown in these two electron micrographs of human soleus muscle cells before and after 17 days in microgravity. Preflight, gravitational load stimulates the production of proteins that keep muscle fibers strong and symmetrical (A). After 17 days in microgravity (B), greatly reduced load on skeletal muscle has slowed protein production in the individual muscle cells, and they have grown more irregular and fragile as they atrophy. The prevalence of white lipid droplets (L) indicates that in microgravity, muscles build fat stores instead of using them for energy.

but the basic principle is simple. Muscles, explains Fitts, are adaptable tissues. Increase the load on them by lifting weights or other types of exertion, and they grow larger and stronger. Reduce the load by lying in bed or living in microgravity, and they grow smaller and weaker.

"When you load a muscle," Fitts continues, "its fibers begin a series of intracellular signaling steps. Genes within the cell nucleus make RNA [ribonucleic acid], which synthesizes proteins that make up muscle fiber. Pumping iron activates the expression of these proteins, which accumulate and enlarge the muscle fibers."

Microgravity has the opposite effect. It reduces the load that gravity naturally places on muscles, interrupting protein synthesis so that fibers begin to atrophy. This loss of muscle mass contributes to reduced skeletal muscle strength when astronauts return to Earth.

Not all muscles atrophy at the same rate in microgravity. Back and leg muscles that work against Earth's gravity to maintain an erect posture waste fastest in microgravity. Yet even among these muscles, there are differences. In microgravity, astronauts naturally assume a modified fetal position, with legs bent at the knees and feet extended downward. This posture shortens the calf muscles in the back of the lower leg, removing tension and speeding atrophy. It also lengthens the shin muscles in the front of the leg, creating enough tension to impede atrophy.

Fast and slow

Microgravity also has a profound effect on fast- and slow-twitch muscle fibers. As the name suggests, slow-twitch fibers contract gradually and generate little power but have high aerobic capacity and resist fatigue. Fast-twitch fibers contract more quickly and generate more power but tire quickly.

"Slow-twitch muscle fibers dominate in running marathons and fast-twitch muscle fibers in the 100-yard dash," says Fitts. Analysis of rats exposed to microgravity initially led researchers to believe that spaceflight degraded slow-twitch fibers more rapidly than fast-twitch fibers, but more recent human studies indicate that both types of muscle fibers undergo significant atrophy.

Surprisingly, spaceflight alters the balance of fast- and slow-twitch fibers. "Not only is there a change in the amount of protein synthesized but also the type synthesized," says Fitts. "During extended flights, about 15 to 20 percent of slow-twitch muscle fibers become fast-twitch fibers." Muscle conversion is likely caused by changes in the type of muscle proteins synthesized by the body, he explains. Changes in fiber type may also be responsible for muscle tears when astronauts return home. "Our theory is that microgravity may suppress expression of proteins that anchor contractile filaments to the muscle fiber surface," he says.

NASA has long understood the importance of exercise in battling muscle atrophy in microgravity. Here, astronaut Robert F. Overmyer works out on a treadmill aboard Spacelab in 1985 (left). Sixteen years later, European Space Agency astronaut Umberto Guidoni works out on a cycle ergometer aboard Space Shuttle *Endeavour* (right). Although these aerobic exercises work the muscles of the upper leg, Fitts believes they may not provide the right types of loads to prevent muscle wasting in microgravity.

credit: NASA

Regimen change?

Any microgravity exercise routine must maintain not only muscle mass but also the right mix of proteins to balance fast-twitch muscle power with slow-twitch muscle endurance while firmly anchoring contractile filaments. This sounds like a tall order, but Fitts believes that preserving muscle mass will automatically balance protein synthesis as well.

Muscle atrophy during spaceflight has always been tough to avoid. Historically, U.S. and Russian astronauts have relied on aerobic exercises, primarily pedaling a cycle ergometer (an exercise bike) and running while tethered to a treadmill. Unfortunately, aerobic exercises are designed to condition the cardiovascular system rather than apply loads systematically to a wide range of muscles, Fitts explains. Cycling, for example, applies a good load to the upper leg but not the lower leg or back, he says. "It does not preserve muscle."

"At this point," Fitts says, "we know we're losing muscle mass and not getting the proper muscle activation with aerobics." Although the ideal microgravity exercise program remains undefined, Fitts believes it will include more strength training.

Strength training, says Fitts, involves two different types of resistance exercises: high-intensity isotonics, which shortens and lengthens muscles (for example, lifting and lowering a dumbbell), and isometrics, which fully contracts muscles without movement (for example, pushing against a doorway). Both types of exercise could potentially reduce muscle atrophy in microgravity. Fitts' experiments with rats, however, suggest that isometrics may protect slow fibers better than isotonics because slow fibers develop very little force during relatively fast isotonic motions.

It is easy to develop a strength training program that combines isometrics and isotonics on Earth. In microgravity, where a dumbbell "weighs" no more than a feather, it is difficult — but NASA may have a solution. Studies are under way to evaluate the efficacy in microgravity of the interim resistive exercise device, which was installed aboard the ISS in April 2001. The device generates up to 300 pounds of resistance for various exercises. (NASA licensed the technology to Schwinn, which now sells it as the RiPP Pro unit.)

Fitts says several research groups are working to develop similar units that could provide adequate loads to protect skeletal muscle while living in microgravity. The challenge, he says, is designing compact, reliable devices that can generate consistent, measurable loads for the various skeletal muscle groups located throughout the body.

Testing

After determining the best kind of exercise for astronauts, the next question is, how much exercise is enough? "If you're pumping iron on Earth, two or three times weekly is enough to build muscle," says Fitts. "In [microgravity], you'll have to do it maybe one or two times per day" — and that's only to maintain muscle strength, not increase it.

The operative word here is "maybe," because the effects of prolonged microgravity on muscle fibers remain largely uncharacterized. Without fully understanding how each type of muscle fiber changes over time, any proposed countermeasures are educated guesses at best. Yet Fitts' guesses are more educated than most. He led a team that characterized human limb muscle fibers for the 17-day STS-78 flight in 1996. Now he has begun to run similar tests on astronauts before launch and immediately after they return from extended ISS missions.

Fitts is studying the two major muscles of the calf: the outermost gastrocnemius, which contains both fast- and slow-twitch muscle fibers, and the soleus underneath, which contains mostly slow-twitch fibers. Instead of measuring gross muscle performance, he is assessing individual muscle fibers from small tissue samples taken from the calf muscles of astronauts before and after spaceflight.

Fitts chemically activates the muscle fibers to cause them to contract so he can measure force, velocity, and power. When the force they generate reaches its peak, he stretches the fibers 10 percent — equivalent to the stretching that occurs during walking or climbing stairs — and measures their peak force again. Muscle fibers from people who exercise on Earth typically show little change in strength after five stretches; Fitts expects postflight muscle fibers to show significant damage after only one or two stretches. Fitts then determines where tears occur in the fibers by examining them with an electron microscope. He also uses antibodies that react with specific proteins in the fibers to identify protein changes. Together, the information helps him

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Research Update: Fundamental Space Biology

Can Microgravity Change a Bacterium's Virulence?

Studying Streptococcus pneumoniae *in orbit may answer some fundamental questions about whether exposure to microgravity changes the bacterium's gene and protein expression and, ultimately, its virulence.*

You may not think of your body as the perfect habitat for bacteria and other microscopic organisms, but numerous microbes are a part of the human body's normal flora. They live on and within the body but seldom cause disease or other problems for their host. Some of these microbes are opportunistic pathogens (they cause disease only when the right conditions are met).

Each astronaut naturally carries a full complement of bacteria and other microbes on every mission, and a low-gravity environment may affect these tiny passengers. Crews on long-term missions may become especially susceptible to microbial infections because of spaceflight's effects on the immune system. Additionally, some researchers wonder whether microgravity increases a microbe's virulence, that is, its ability to cause disease. In short, the space environment could bring out the worst in these organisms. But how?

Principal Investigator David Niesel, chair, ad interim, and professor in the Department of Microbiology and Immunology at the University of Texas Medical Branch in Galveston, is studying whether exposure to microgravity alters *Streptococcus pneumoniae*, a bacterium that normally resides in the human nasopharynx (respiratory tract). Niesel is particularly interested in how the expression of *S. pneumoniae* genes and proteins change on exposure to microgravity and how these changes may be linked to an increased ability to cause disease.

A regulatory issue

S. pneumoniae normally does not cause disease in healthy adults, but it is a leading cause of middle ear infections in young children. It is easily spread by aerosols (for example, by sneezing or coughing) and can be responsible for cases of community-acquired pneumonia or bacterial meningitis, but people who are susceptible to such infections typically have improperly functioning immune systems (babies, the elderly, and people who take immunosuppressive drugs or are infected with human immunodeficiency virus [HIV]). The organism could also become more pathogenic in response to environmental factors. Part of what may make the organism change from its normally benign state to cause disease are changes in the messages produced from the deoxyribonucleic acid (DNA) that encodes the microbe's genes.

All cells, including bacteria, contain DNA that provides the blueprint used to encode ribonucleic acid (RNA) messages that direct the production of the various proteins that allow the cells to conduct their daily business. Depending on the needs of the cell, production of the message from certain genes is turned on or off (expressed or not expressed) to produce specific proteins that allow the cell to perform particular functions. The process of turning genes on and off is known as gene regulation.

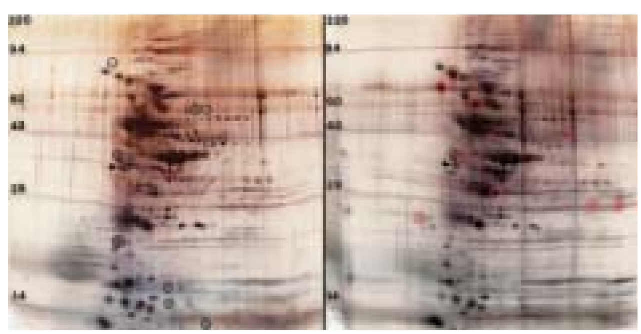
Niesel is studying gene regulation as a way to determine whether exposure to the spaceflight environment alters the ability of an opportunistic bacterial pathogen like *S. pneumoniae* to cause disease. For example, *S. pneumoniae* requires proteins known as adhesins to be able to attach to epithelial cells lining the respiratory tract. If exposure to microgravity turns on the genes that code for adhesin production, then the bacteria may be better able to attach to those epithelial cells, thus encouraging a process that is necessary for the initiation of disease.

Niesel's research is made easier by the fact that the *S. pneumoniae* genome has been completely sequenced and annotated; not only are all of the approximately 2,400 genes of the bacterium known, but many of the proteins that those genes encode for are also well characterized. So, Niesel hopes to be able to track changes in the expression of all this microbe's genes.

"The most fundamental question," says Niesel, "is to ask what alterations there are in gene expression and protein expression under those unique conditions [in the space environment]. And then the corollary to that is, with those changes, is there any indication that the organisms' virulence would be increased in such an environment?"

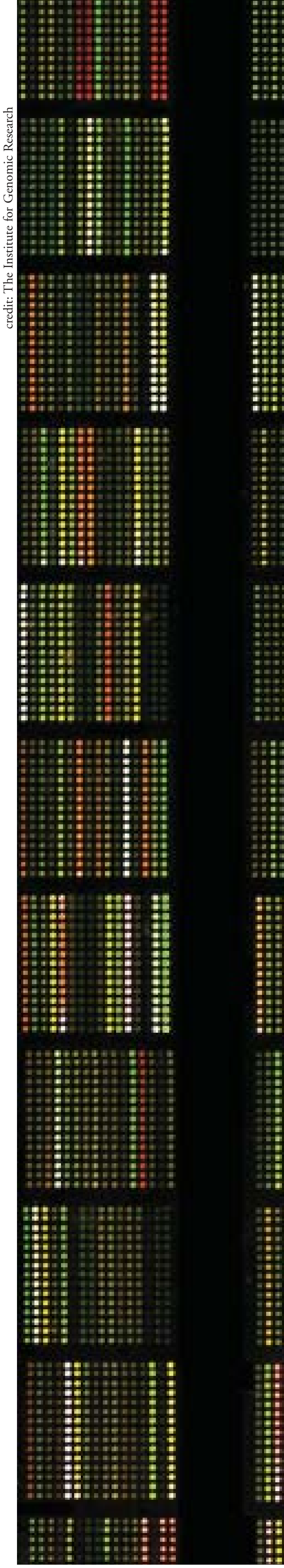
In the beginning

Niesel and his research team have used a unique piece of NASA-developed equipment — the high aspect ratio vessel



credit: David Niesel, Carlos Orihuela, David Watson

These gels, obtained by two-dimensional (2D) electrophoresis (in which proteins move different distances through a polyacrylamide gel matrix based on their molecular weight and total charge in an electric field), illustrate Principal Investigator David Niesel's findings: that exposure to modeled microgravity results in some of *Streptococcus pneumoniae's* proteins being upregulated and others being downregulated. In 2D protein profiles of whole cell lysates of *S. pneumoniae* 6304 cultured under normal gravity (left), black circles mark proteins that appear to be expressed at higher levels under normal gravity conditions. In proteins from *S. pneumoniae* 6304 grown under modeled microgravity in a high aspect ratio vessel (HARV; right), red circles mark proteins that were expressed at higher levels under modeled microgravity.



A deoxyribonucleic acid (DNA) microarray slide such as this one contains oligonucleotide fragments representing all genes of *Streptococcus pneumoniae*. Researchers use DNA hybridization techniques to hybridize dye-labeled probes to the genes spotted on the array. The dye-labeled probes are detected with a laser, which allows researchers to determine which of *S. pneumoniae's* genes are expressed exclusively, or show altered expression, after culturing in microgravity (modeled or actual).

credit: The Institute for Genomic Research

(HARV) — to model the effects of microgravity on *S. pneumoniae* growth. The HARV is a rotating bioreactor that keeps the growing cells in a constant state of multidirectional acceleration, thereby simulating in the laboratory the microgravity conditions of freefall that occur in orbit. Niesel's team compared growth, protein expression, and virulence activity of the HARV-grown bacteria with those of control cultures grown in the lab under normal gravity conditions.

"We've looked at some really fundamental things in terms of bacterial growth and properties," says Niesel. Bacteria in the two cultures do not grow at different rates, nor do they divide at different rates. Additionally, these bacteria normally appear in pairs or short chains, and the length and morphology (appearance) of chains in the HARV cultures do not appear to be different from those of the control cultures. But an important difference was observed: Adherence of the bacteria to epithelial cells lining the respiratory tract was enhanced in the HARV cultures — and the ability to adhere is directly related to potential to cause disease.

"We have also done a series of experiments looking at total protein expression by these bacteria after they have been grown in the HARVs and compared that to laboratory controls," says Niesel. "Using two-dimensional polyacrylamide gel electrophoresis — in which an electric field is used to separate proteins on the basis of molecular weight and total charge — we can find [in the HARV-grown cultures] about 19 different proteins that are overexpressed, and we have 12 proteins that are underexpressed compared with the laboratory controls." The altered production of these proteins indicates that the bacterium is responding to the modeled microgravity conditions with altered gene and protein expression.

The team noticed that one protein appeared prominently on several gels, so they extracted that protein from the gel and used a mass spectrometer to identify it. The protein turned out to be one of the predominant adhesin proteins produced by *S. pneumoniae*. Says Niesel, "That reinforced the result we saw with the increased adherence of the bacterium to the respiratory epithelial cells [in the HARV-grown cultures]." These results suggest that the gene that encodes the adhesin protein is turned on (upregulated) as a result of exposure to modeled microgravity.

"Similarly, we have some preliminary evidence that a protein that is important to the [bacterium's] resistance to trimethoprim-sulfamethoxazole, a compound that has antimicrobial activity, is also upregulated under conditions of modeled microgravity," he continues. "That's an interesting observation, too, because there's some evidence from spaceflight that suggests that bacteria become more resistant to antimicrobials in the space environment."

These ground-based experiments have given the researchers some clues as to which genes, proteins, and pathogenic properties they need to monitor when they go to the next stage of research — sending *S. pneumoniae* into orbit.

Color-coded genes

When he conducts his experiment aboard the International Space Station (scheduled for 2004), Niesel will use DNA microarray technology from the Pathogen Functional Genomics Resource Center at the Institute for Genomic Research in Rockville, Maryland, to determine which *S. pneumoniae* genes are turned on or off as a result of exposure to modeled or actual microgravity.

DNA microarrays are simply glass slides on which oligonucleotides (short chains of nucleotides — the building blocks of DNA and RNA) specific for each of the individual genes of an organism are "spotted." Once Niesel's experiment on the International Space Station is complete, he will create labeled copies of the expressed genes as complementary DNA (cDNA) from the bacteria grown during modeled or actual microgravity, or in control experiments under normal gravity. The cDNA from the microgravity samples (modeled and actual) and the normal-gravity controls will be labeled with different dyes (red and yellow, respectively) to distinguish them and then used to probe the DNA microarrays.

Samples of dye-labeled probes from the experimental and control cultures will be placed onto the microarray slides under hybridization conditions, and these labeled probes will bind with "matching" oligonucleotides spotted on the plate. After hybridization occurs, the probes will be washed off the slide, leaving behind only the dye-labeled probes specifically bound to spots representing individual *S. pneumoniae* genes on the microarray. The probes and the gene sequences they are bound to will be detected by a laser that can be used to quantify the bound red or yellow dyes. An image of the microarray will be created and stored on a computer.

When the hybridized microarray image is viewed, the spots representing genes will appear red, yellow, green, or black (no color). If the cDNA probes from the bacteria cultured under modeled or actual microgravity were labeled with the red dye and those from the normal-gravity control bacteria with the yellow dye, then red images above specific genes will represent genes that were exclusively expressed in bacteria cultured in microgravity (modeled or actual). Green images will indicate genes that were expressed under both conditions. Furthermore, the shade of green will represent the extent to which the genes were differentially expressed in the experimental groups (for example, a green spot with a significant red component will indicate that the gene was turned on to a greater extent in the microgravity-exposed

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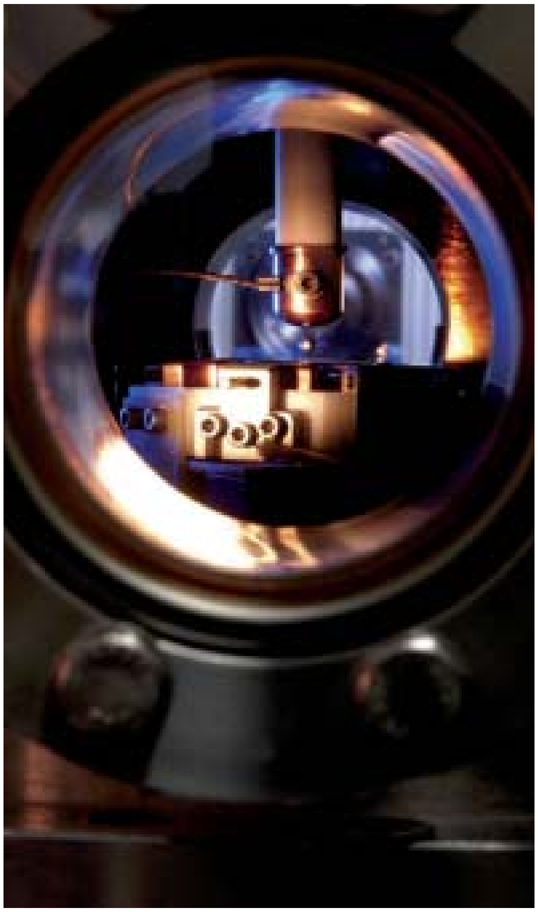
Research Update: Physical Sciences Research

Freezing Is Hot Topic

How can water and molten metals remain liquid well below their expected melting temperatures? Ken Kelton seeks answers on Earth and in microgravity about the still-mysterious physics of crystallization.

Chill water to 0°C (32°F), and it freezes into ice, right? Well, not necessarily.

As long ago as 1721, the German-born Dutch physicist Gabriel Daniel Fahrenheit — inventor of the mercury thermometer and the Fahrenheit temperature scale — discovered that vials of undisturbed pure rainwater could remain liquid at temperatures as low as –9°C (15°F).



credit: Emmett Given, ARCATA

NASA's Electrostatic Levitator enables scientists to study solid and molten samples without containers, which can contaminate and compromise science experiments that require pure samples. Containerless processing was essential to investigator Ken Kelton's observation of how liquid metals crystallized into solids. Here, a charged solid sphere of titanium–zirconium–nickel alloy is suspended in the device between electrodes above and below the sample, ready to be heated by a laser beam (not shown).

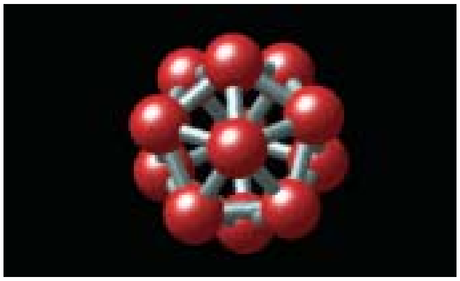
Indeed, his samples actually seemed to resist freezing. The ability of some substances to remain liquid well below their melting temperatures has fascinated physicists ever since. Fahrenheit also observed that physical vibrations, chemical impurities in the water, or imperfections or dirt on a container's walls usually help ice crystals begin to nucleate (form). But pure water, if undisturbed, can be cooled to temperatures far below 0°C and remain liquid.

By the early 1950s, even metals and alloys had been observed to remain liquid when cooled to tens or even hundreds of degrees below their melting temperatures. In 1952, British physicist Charles Frank proposed an atomic theory to explain this phenomenon, called undercooling. But because technology was limited, no one could see what the atoms inside these undercooled liquid metals were actually doing.

Recently, the combination of an inventive research team, a source of high-intensity X-rays, and the NASA Electrostatic Levitator has made it possible to test Frank's theory. Kenneth F. Kelton, professor of physics at Washington University in St. Louis, Missouri, leads the team that has observationally verified Frank's half-century-old hypothesis for the first time and is now devising an experiment to take place aboard the International Space Station to further explore the physics of undercooled metals. His work could revolutionize physical theories of crystallization, with implications for materials processing on Earth as well as in space.

Early notions

Frank built his 1952 theory about the behavior of undercooled metals on the notions of scientists who came before him, including Fahrenheit and the 19th-century American chemist J. Williard Gibbs. Gibbs was intrigued by the fact that water often exists simultaneously in more than one phase (ice, liquid, and vapor). Gibbs



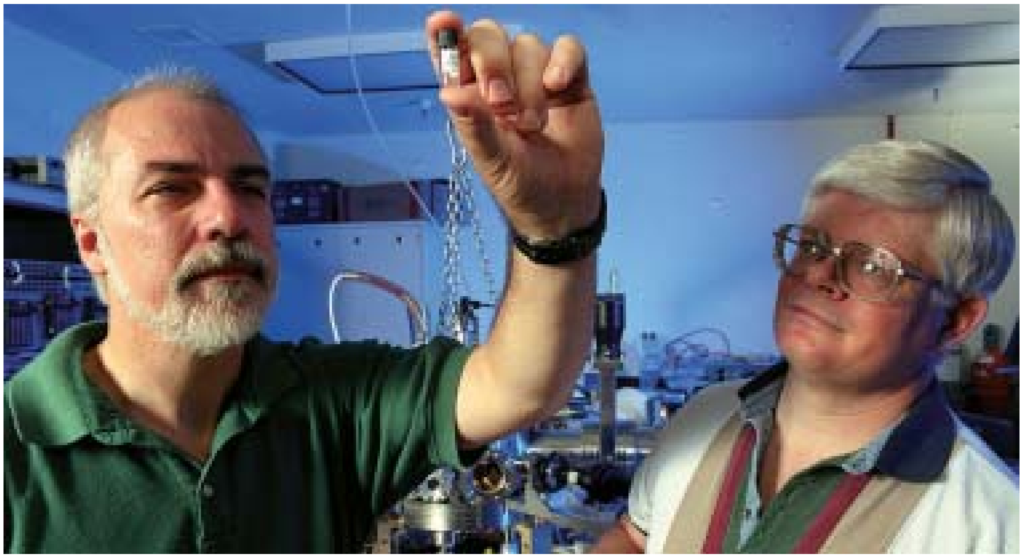
credit: Washington University

An icosahedron, a three-dimensional geometric figure with 20 triangular faces, is the minimum-energy structure that atoms can assume; when sighted along one of its vertices, as seen here, the combination of triangular faces yields a pentagon. Ken Kelton's recent experiments with NASA's Electrostatic Levitator have validated a theory that explains why a molten metal can remain liquid despite being cooled to well below the temperature at which it should begin to solidify.

hypothesized that some kind of "energy barrier" must inhibit water from transforming from one phase to another, because changing phase necessitates the creation of a surface or interface between droplets and vapor or ice.

Now, physicists know that when a liquid changes into a crystalline solid, its atoms or molecules must rearrange themselves from an amorphous (random) hodgepodge to a specific regular (fixed) order that can be repeated indefinitely in three dimensions. The atoms (or molecules, depending on the nature of the chemical bonds) assume a regular order because they seek a structure that requires the least energy. In the case of water, the surface that is created between small ice particles and liquid water as water changes phase, however, acts as a high-energy barrier opposing the wholesale rearrangement of the water molecules and the formation of ice nuclei — thus explaining why water can be undercooled. Continuing to decrease the temperature, however, reduces the energy barrier because of an increasing thermodynamic need to crystallize. Eventually, the thermal energy of the molecules in the liquid water becomes greater than the energy of the barrier, freeing the molecules to rearrange themselves into a crystalline structure, and ice begins to nucleate.

Undercooled water can remain liquid indefinitely, until some local fluctuation allows the system to overcome the energy barrier to solidification. When crystals start to form, the evolved heat of fusion — that is, energy the mass releases as heat when it crystallizes into a solid (which, remember, has a lower-energy structure) — raises the temperature of the liquid, providing enough thermal energy to solidify the entire mass quickly. (Evolved heat of fusion is also what causes liquid plaster to become quite hot as it solidifies.)


credit: Washington University

Investigator Ken Kelton (left) of Washington University, St. Louis, Missouri, and co-researcher Michael Robinson (right) of Marshall Space Flight Center, Huntsville, Alabama, examine a sample metal alloy processed in NASA's Electrostatic Levitator. This sample and others that Kelton's team has processed have answered a mystery that Kelton has been trying to solve since 1985: how can molten metals resist solidification?

Frank's take

The 20th-century finding that elemental metals (and metal alloys) also could be undercooled stumped physicists; the densities of molten and solid metals (unlike those of water and ice) are so similar that physicists expected the energy barrier between them to be very small. So, why should metal atoms in the liquid "feel" a barrier to their rearrangement into crystals? How could molten metal, like water, resist solidification?

Frank had a radical answer to this question. He hypothesized that the atoms of undercooled liquid metals are actually arranged quite differently from those that form solid (crystalline) metals, and that this fundamental structural mismatch creates an energy barrier to the formation of crystalline solids.

Specifically, Frank hypothesized that in small local volumes in an undercooled liquid metal, the atoms spontaneously arrange themselves in an icosahedron, that is, a three-dimensional structure that has 20 triangular faces. Why an icosahedron? Frank believed that a cluster of icosahedrons would be the lowest-energy local structure that the atoms could assume.

An icosahedral structure neatly explained why metals resist cooling. In many ways, an icosahedron can be regarded as a three-dimensional version of the two-dimensional pentagon. But just as a floor can't be completely covered with pentagonal tiles without gaps, icosahedral clusters can't be packed to form a crystal without defects. In other words, in two dimensions, only a few fundamental shapes — squares, rectangles, equilateral triangles, and hexagons — can tile a floor periodically (i.e., out to infinity); in three dimensions, only clusters of atoms in certain specific structures (e.g., cubes and tetrahedra) can pack to form periodic crystals. But locally, such a periodic crystalline structure in solid metal has a slightly higher energy than a single icosahedral cluster. Thus, additional energy is required to separate icosahedrally ordered atoms in liquid metal slightly so they can rearrange themselves to form a solid periodic crystal. That requirement for additional energy, Frank hypothesized, explained the energy barrier to nucleation (nucleation barrier; i.e., why metals resist solidifying and can be undercooled).

There was just one hitch. When Frank came up with this idea in 1952, no one had ever seen icosahedrally ordered atoms in a liquid. Frank's hypothesis about local icosahedral order remained a mere hypothesis for decades.

In the 1980s, physicists discovered a host of novel hard, brittle compounds that were dubbed quasicrystals. Quasicrystals have perfectly ordered and stable atomic structures, just like crystals do; but quasicrystals are not periodic. Then how can they exist as solids? Thinking about floor tiles again brings the point home. Although pentagonal floor tiles will leave gaps, British cosmologist Roger Penrose showed that pentagons can be combined with other shapes to tile the floor nonperiodically, so it has no gaps but still retains local pentagonal order. A similar situation likely accounts for how solid icosahedral quasicrystals manage to exist, but its identification is still a matter of intense scientific study.

Tools for testing

The discovery of solid icosahedral quasicrystals provided a key to test Frank's hypothesis of local icosahedral order in undercooled liquid metals. But, Kelton explains, achieving the proper environment and adequate measuring tools required the development of two pieces of sophisticated research machinery: a source of high-intensity X-rays and a device that can levitate a drop of molten material.

X-ray diffraction techniques for probing the structures of solids have existed since before Frank's day. A crystal sample is bombarded with X-rays, photographs or detectors measure how the X-rays are diffracted (scattered) by the crystal's atoms or molecules, and then the atomic or molecular arrangement is determined by mathematical analysis of the diffraction pattern.

The rate at which data could be obtained by X-ray diffraction in the 1950s was very slow, relying largely on photographic methods. Crystallization within an undercooled liquid metal happens so fast, however, that measuring it requires high-speed, high-resolution techniques. It also requires X-rays with unusually high intensity that can be obtained only from synchrotrons, which did not exist until the 1980s.

Studying an undercooled liquid metal also entails maintaining a scorching-hot droplet still enough to study it while keeping it away from any container walls,

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Robotic Rover Could Turn Moon Dust into Golden Opportunities

Just a few days' travel from Earth, the Moon awaits the return of human footsteps. Metal oxides in its dusty surface could help transform the lifeless lunar environment into a surface capable of producing electricity.

December 1972 marked the last time humans set foot on the Moon. Although more than 30 years have passed since then, Moon rocks carried back from the Apollo missions continue to help scientists figure out how to support a prolonged lunar visit. Even though the Moon has no atmosphere, people could make extended stays on and eventually colonize the Moon if sustainable supplies of oxygen and power could be produced. In fact, the dusty debris of meteors strewn across the lunar surface contains sources for both.

Five years ago, Alex Freundlich and Alex Ignatiev, two materials scientists at the University of Houston, Texas, read a paper in which a method of extracting oxygen from metal oxides (silicon dioxide or iron oxide) in lunar soil was described. They weren't as interested in the results, though, as they were in the waste products of the technique: silicon, aluminum, and iron, the building blocks of electronic devices. "Once you have silicon, you can make solar cells and make electronic circuits," says Freundlich. They wondered whether refining alloys from lunar dust was indeed possible. Could thermal energy (from sunlight) and a vacuum (the lunar environment) turn Moon dust into a power source?

This question became the kernel of a project Freundlich now heads at the University of Houston's Texas Center for Superconductivity of Advanced Materials (TcSAM), a NASA research partnership center. Ignatiev serves as center director and Freundlich as principal investigator in designing a robot-controlled Moon rover to make solar cells from lunar resources.

Lunar pioneers

When settlers explored the American West, they took hand tools and built what they needed from the resources they found. Although a robotic rover is more complicated than an ax, the principle is the same. "Human exploration of any [planetary] surface will require making use of local resources," says Ignatiev.

As with any exploratory mission, storage space and horsepower to propel the vehicle and its cargo are limited. So, choosing tools to construct a power source on the Moon is a critical decision. Bringing the tools to build a nuclear power plant would be difficult, says Ignatiev. Transporting solar panels would be easier, but they are large and heavy. Interestingly, the solar cells themselves form a thin film only a few microns (1 micron = 3.94×10^{-5} inches) thick; 99 percent of the panel's weight lies in the support structure. "That's where our idea really was," says Freundlich. "The Moon is a big piece of rock with metal oxides. If lunar soil could be used to fabricate the support structure, then solar cells could be deposited on top of that structure."

Solar panels made by a Moon rover wouldn't be cutting-edge or even high-performance devices. They would simply do what they are made to do — turn sunlight into electricity. Their efficiency would be moderate at 5–12 percent; that of the best solar cells on Earth is around 30 percent. But they would be good enough, and according to Michael Duke at the Colorado School of Mines in Golden, who helped figure out the economics of the project, taking the tools and making solar panels on the Moon would be more cost-effective than launching solar panels from Earth.

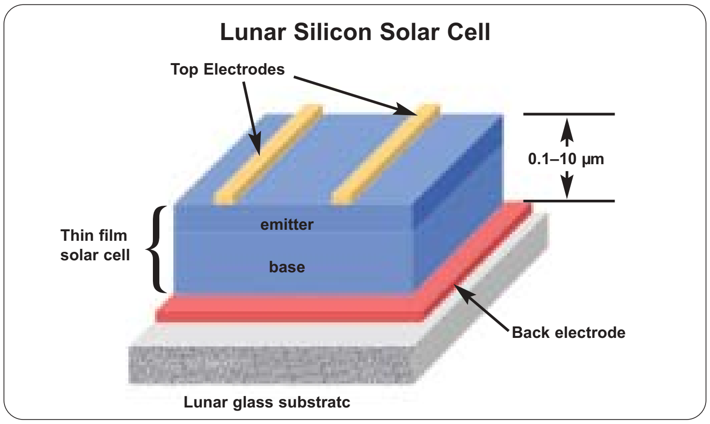
A sunny spot with good soil

For now, Freundlich and his team are weighing two fabrication options: build solar panels on site from only lunar resources, or bring high-quality material from Earth to build the solar cells and create only the support structures from lunar soil. Which option is eventually chosen will depend in part on the landing site selected, which in turn will depend on soil composition, the type of mission the power would support, and Sun incidence (which would determine the amount of power the panels could produce). Finding a spot that satisfies all these needs is tricky.

Lunar soil will play three roles in establishing a lunar base. First, the rover will melt lunar soil and construct the substrate, which will serve as a base or support structure for each solar cell. Second, the rover design includes a way for silicon to be purified from lunar soil and deposited onto the substrate in thin film form, although Freundlich and Ignatiev may decide to ship thin-film semiconductor materials from Earth. Third, the rover will be designed to deposit electrode materials extracted from lunar soil onto the substrate.

The solar panels will be assembled from regolith, a mixture of crushed rock and debris that covers the Moon and some planets, including Earth. The composition of lunar regolith (that is, the relative amounts of metals such as silicon, iron, and aluminum) varies with location, like it does on Earth. Iron and aluminum may not pose problems when regolith is melted, but they will need to be removed before silicon is deposited onto the substrate (to create the thin-film solar cells). Sanders Rosenberg at In-Space Propulsion Ltd. (Sacramento, California) and Darby Makel of Makel Engineering (Chico, California) are helping Freundlich's team figure out how to purify lunar regolith by removing problem metals.

Like soil composition, the quality of sunlight received at different areas of the



credit: Texas Center for Superconductivity of Advanced Materials

All layers of a solar panel can be fabricated from lunar regolith. This illustration is a cross section of a solar cell 0.1–10 microns (µm) thick on a substrate, both of which can be made from lunar soil.

Moon varies. The Moon's south pole could easily support panel fabrication because of good soil quality, says Freundlich, but the sunlight incidence is almost parallel to the surface, which means that the solar panels would need to be installed vertically or on inclined surfaces, such as hillsides. At the Moon's equatorial region, sunlight radiates at a good angle for capturing solar energy; however, the Sun shines there in 14-day light–dark cycles, leaving the region in darkness for 2 weeks at a time. Either of these locations would require additional tools and materials that would add significant launch weight to a mission.

Moon rover

Once the mission and landing area have been chosen and the rover has reached its destination, the next step will be to fabricate the solar panels. Constructed in layers, solar panels begin with a substrate that supports the structure and insulates the panel, preventing electrical leakage. Then, one strip of metal electrodes and layers of semiconductive material are applied, all topped off with another layer of electrodes.

The Moon rover, currently proposed to be about the size of an office desk, would roam the lunar surface at 1 meter per hour in a preprogrammed pattern. To begin the construction of each solar cell, a solar energy concentrator on the front of the rover would smooth the regolith and heat it to a high temperature, turning the lunar dust into a dark, glassy substrate about 20 centimeters wide by 10 centimeters long (7.87 inches by 3.94 inches), at least in the initial design. To create the solar cells, the rover itself would use solar energy to evaporate the elements needed (either metals and semiconductors extracted from the regolith or raw materials carried from Earth) and deposit them on top of the substrate. The Moon's vacuum environment would make this a thin-film solar cell measuring 15 centimeters wide by 10 centimeters long (5.91 inches by 3.94 inches). The rover will make 10 cells per hour; 100 cells connected in a series will constitute a panel operating at about 100 volts, said Ignatiev.

The conceptual rover will operate robotically, with remote intervention; scientists on Earth will monitor the operations via camera in the same way that Mission Control monitors human flights. "On the ground, a crew of engineers with knowledge of the experiment will provide telemetry, making sure the rover travels through its preprogrammed sequence, and make any modifications if needed," says Freundlich.

After 1 year of operation, the rover should have made enough solar panels to generate 200 kilowatts of available electrical power — enough to support a colony of 10–50 people and their scientific endeavors, depending on the mission. Although it's difficult to speculate on the amount of electricity a research mission might need, on Earth, it takes nearly 1 kilowatt of electricity to power a toaster.

The next giant step

For now, the Moon rover exists only on paper, but solar panels have been successfully built from lunar resources in the laboratory using regolith provided by NASA.

The next step will be to build a prototype rover and test it in one of NASA's lunar surface simulators. And that's not the final hurdle. Because the process of building the panels will require not only a flat surface but also a surface free of Moon rubble, a way must be found to clear a site. One possibility is to send one rover rugged enough to bulldoze the regolith and clear debris and another that could perform the precisely controlled movements needed to fabricate the solar panels. "It's going to be rough terrain," says Freundlich. "It's going to be like making a building operation in the Sahara desert."

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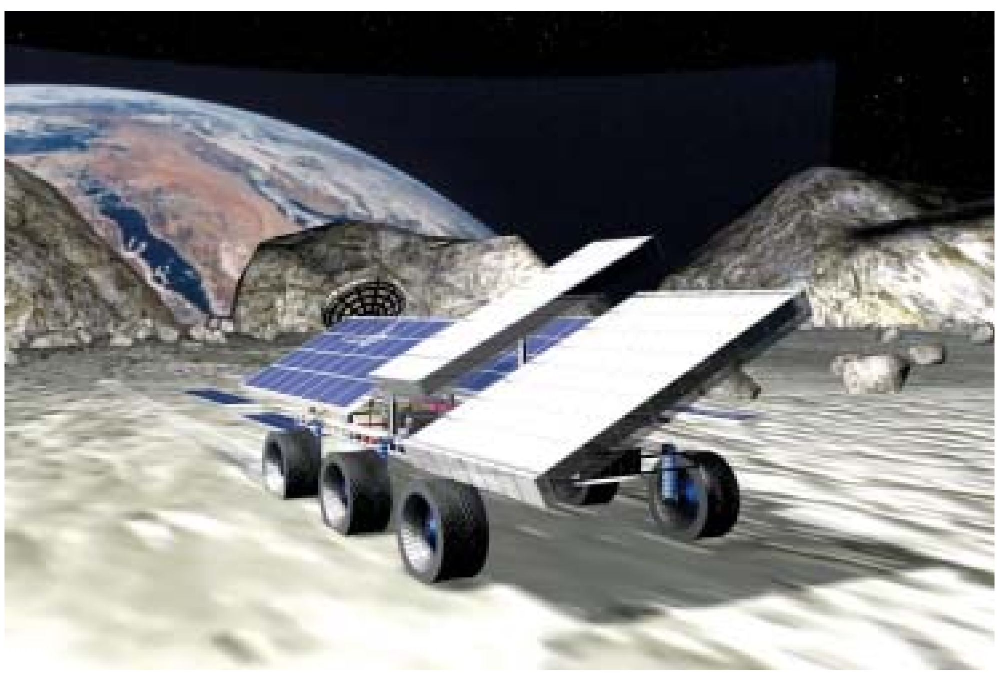


credit: Sasakawa International Center for Space Architecture at University of Houston

This drawing illustrates one design for a rover that would manufacture solar panels on the Moon while being controlled remotely — from Earth.

Towers of Virtual Science

With the new NASA @ your library program, students across the country are learning about some amazing biological and physical research in space — and having fun to boot!

Stately 3-meter (10-foot) steel towers crowned with bright banners are beckoning hundreds of thousands of visitors across the nation to explore the treasures they hold within: the wonders of microgravity research. The open towers house NASA's newest traveling exhibit, NASA @ your library. The exhibit captures the attention of young scientists- and astronauts-to-be as well as adults from all walks of life through interactive video clips, in-depth videos, and live presentations. In partnership with the American Library Association (ALA), NASA's Office of Biological and Physical Research (OBPR) is letting the public know about the vast array of research that scientists conduct on Earth and astronauts carry out on the International Space Station (ISS) and how that research relates to everyday life.


credit: NASA

The NASA @ your library traveling exhibit uses the "cool factor" of space to interest students in math and science and to make people of all ages aware of the unique benefits gained on Earth from scientific research conducted in microgravity.

"The public tends to equate NASA with launches, not scientific research on the ground and in the microgravity environment of space," says Elsie Weigel, OBPR public outreach officer. "In reality, all the scientific research it takes to travel to and set up a new living and working environment on the ISS, the Moon, or another planet changes our life on Earth constantly."

The NASA @ your library exhibit is an effective way to raise awareness. Weigel explains, "I was charged to get the message of NASA's research 'to every town in the United States.' I chose libraries because they draw in all segments of the community and can help local citizens research any space topic." A web site with interactive games on many of the research topics covered in the exhibit helps reach communities beyond those scheduled to host the exhibit (see sidebar, "NASA @ your library Web Site").

NASA @ your library was developed as a first-time joint venture between NASA and the ALA and is managed by the Association for Library Service to Children (ALSC). The program uses the "cool factor" of space to interest students in math and science, make students and parents aware of the unique benefits of conducting scientific research in orbit, and show how ordinary life on Earth benefits from the findings of space research.

Traveling towers

To reach the widest possible audience, several identical exhibits have embarked on 2-year road trips throughout five U.S. regions until the end of June 2005. Each participating library hosts the exhibit for 1 month.

Participating libraries prepare for the arrival of the exhibit by promoting their upcoming "NASA Month," that is, the period during which the exhibit will be on site. Weigel explains, "Each city or town does something different. For example, in Palm Springs, California, the mayor proclaimed October [2003] as NASA Month, and volunteers streamed NASA @ your library banners all over town and provided hats and T-shirts."

One eye-catching feature of each exhibit is a hexagonal tower that covers about 3.4 square meters (144 square feet). It is outfitted with six flat-screen iMac computers furnished by Apple and six adjustable-height stools for "kids" of all sizes. The computers are programmed to play 3-minute videos that each answer one of around 70 questions related to microgravity research and space travel. Example topics range from pure science ("how do candle flames burn?" and "how do water droplets behave in space?") to the history and future of space travel ("how does the space shuttle work?," "how are astronauts chosen?," and "what would it be like to live on Mars?").

So far, the computers have been very popular, especially with younger visitors. Says Margo Wilson, children's librarian at the Spartanburg County Public Library in Spartanburg, South Carolina, "This is the most popular exhibit we've ever had, and the computers have been in constant use!"

A second component of the exhibit is a smaller, rectangular tower (covering about half the floor area of the hexagonal one) that houses a 127-centimeter (50-inch) plasma screen that continually plays videos about what NASA research has contributed to human health, home and transportation, agriculture and the environment, or commerce — a different topic each week. Librarians may invite groups of people from the community who would be especially interested in specific topics; for example, for the week featuring NASA research contributions to health, the library might invite health care professionals to attend a special viewing.

Just in case you were wondering, the exhibit's audio system is acoustically designed not to disturb the regular library patrons. Visitors watching a video stand under one of two audio domes suspended from the exhibit's framework. Up to 10 people can stand beneath each dome and hear what sounds like a normal volume. Outside each dome, however, the sound is heard at only 20 percent of the normal volume, so it is not distracting to other library patrons.

A third component of the exhibit is a display of books related to NASA research that may be checked out by members of the public. Pat Brown, who coordinated the exhibit for the Spartanburg County Public Library, recalls, "Books related to the exhibit were snatched up!" (A list of suggested materials is posted on the NASA @ your library web site, *https://members.ala.org/nasa/*.)

NASA provides a $1,000 stipend to each participating library for purchasing new space-related books to add to their permanent collections. Libraries also use the funds to cover expenses for NASA Month receptions, education programs, or required training session expenses.

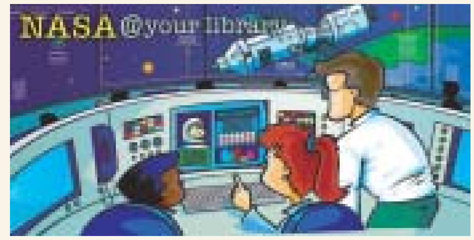
Heralding the good news

So far, the NASA @ your library program is accomplishing exactly what NASA and the ALA had set as a goal to indicate success: attracting increased numbers of visitors to libraries to experience the exhibit. During the opening month of July 2003, an estimated 250,000 library patrons visited the five debut exhibits. During the same month, the new NASA @ your library web site was viewed by 14,000 visitors. Each month the local television networks of the five hosting cities and towns are offered live interviews with astronaut Roger Crouch for their evening news and other programming. "Live shots" in Baltimore, Maryland, and Reno, Nevada, during July reached estimated audiences of 375,000 and 175,000 viewers, respectively. At this rate, millions of people will visit NASA @ your library in one way or another during the scheduled tour.

But what do those numbers really mean? Says Weigel, "We set out with five goals. The numbers indicate high interest in this exhibit. If the exhibit and web site spread the word about [OBPR] research, get the public enthusiastic about NASA programs, inspire the audience to learn more about how science impacts daily life, interest the public in technology, and draw new audiences into libraries, then the tour will be considered successful."

Julie Moberly

NASA @ your library Web Site



credit: American Library Association

The NASA @ your library web site features games about science research in space as well as suggested reading lists for children and adults.

Students who want to learn about microgravity research and space travel can find information at the NASA @ your library web site, *https://members.ala.org/nasa/*. The site features interactive games for students aged 5 to 12 that explore such phenomena as how things burn in microgravity, how fluids behave in space, how astronauts sleep in space, and how NASA and its partners are building the International Space Station (ISS). These activities cover some of the same topics as the video clips that visitors can see at the NASA @ your library exhibit.

The site also offers tips on how adults can help students make the most of their visit to the site as well as reading lists for all ages about research conducted on the ISS.

The NASA @ your library web site is hosted by the American Library Association and features science content from the NASA Office of Biological and Physical Research.

Visit the NASA@ your library web site at *https://members.ala.org/nasa/*. To see when the traveling exhibit will be visiting a library near you, go to *http://www.ala.org/content/navigationmenu/alsc/nasa_@_your_library_exhibit_tour_schedule.htm*.

What's Happening on the International Space Station?

In addition to conducting science and maintenance activities in orbit, ISS Expedition 7 crewmembers Edward Lu and Yuri Malenchenko have made time to reach out to students on Earth.

Before heading back to classrooms this fall, some college students had a unique opportunity to talk directly with International Space Station (ISS) Science Officer Edward Lu and Mission Commander Yuri Malenchenko. On August 6, 2003, Lu and Malenchenko spent nearly an hour answering questions from NASA co-op student employees at Johnson Space Center (JSC) in Houston, Texas, and NASA Academy students at Goddard Space Flight Center (GSFC) in Greenbelt, Maryland, via audio and video downlink. (Co-operative students at JSC are upper-level college students who alternate school semesters with semesters of work in their area of interest at JSC. The NASA Academy is a summer intern program that promotes leadership development and is open to upper-level undergraduate students and first-year graduate students who are interested in aerospace careers.) For the students, it was a chance to ask astronauts questions about scientific research on the ISS and about what it is like to live and work in microgravity.

The event started with an introduction by John McCullough, ISS lead flight director, who summarized the role of Lu and Malenchenko aboard the ISS. He noted that they spend significant time on payload medical and science activities. Among their post-*Columbia* goals, said McCullough, "is validating that we can continue to do the operations we need to do with [only] two crewmembers."

Next, a live downlink was established from the ISS to JSC, and the students at GSFC viewed the event in real time on NASA TV. Both groups had audio links to the ISS so they could pose questions directly to Lu (the main spokesperson for this event) and Malenchenko, who were perched near the Microgravity Science Glovebox (MSG).

One of the first questioners asked Lu what experiments were being conducted in the MSG. Lu replied that he could not open the MSG on camera because the Pore Formation and Mobility Investigation (PFMI) was proceeding inside. This experiment is studying the solidification of alloys in microgravity. He explained that although there is a good theory to explain the solidification process in metal alloys, it has never been verified because on Earth, gravity-driven buoyancy dominates the movement of any bubbles that form in liquid metal, hindering scientists from observing slight influences on their dynamics. "To verify your basic theory, you want to do it in a location like this," he explained, because in microgravity, buoyancy is minimized, allowing for the in-depth study of bubbles' subtle behavior.

credit: NASA

Expedition 7 Mission Commander Yuri Malenchenko (left) and International Space Station Science Officer and Flight Engineer Edward Lu (right) pose in the Destiny Laboratory of the ISS wearing Russian Sokol suits.

Lu stated that the most interesting or unusual thing the crew had observed while conducting experiments were bright flashes emanating from an aurora on Earth. "No one that we know of has ever reported any flashes, any type of bursting behavior in auroras, and we've been able to rule out a couple of simpler explanations," he said.

Another student wanted to know whether the brain is affected by exposure to microgravity. Replied Lu, "A lot of astronauts joke about 'space stupidity.' What I think it really means is that when you get very, very busy up here, there is a tendency to forget some things." He remarked that he didn't think this was so much a result of exposure to microgravity as an effect of juggling multiple tasks over long workdays.

A student at GSFC asked whether Lu and Malenchenko were finding it difficult to accomplish necessary operational tasks and still find time for science experiments and leisure activities, given their small crew. Said Lu, "I think we're showing that … the program … [can] operate this [the ISS] and still do quite a bit on the side." He added, "I want to stress that a lot of the science we do up here is not your classic science experiments. A lot of research is simply on running a space vehicle. I think the main purpose of the space station is [to learn] how to run long-duration spaceflight [and] how to run it as an international program — and that is something we are learning every day. I'm not sure if that qualifies as operations or research, but it really is kind of both.

"From the technical point of view, we're going to gain knowledge we need to explore the solar system, which I think is our destiny," he continued. Malenchenko added that he felt that the ISS represented "a huge opportunity" to continue peaceful programs that would "benefit all people on Earth."

Julie K. Poudrier

For more information about current Office of Biological and Physical Research activities on the International Space Station, visit the Research on Station web site, *http://spaceresearch.nasa.gov/research_projects/ros/ros.html*. To access "Greetings, Earthlings," Edward Lu's letters from the ISS, visit *http://spaceflight.nasa.gov/station/crew/exp7/luletters/lu_letterlatest.html*. To learn more about the Pore Formation and Mobility Investigation, read "Solidifying the future" in the June 2003 issue of *Space Research* (pages 16–17).

Meetings, Etc.

TECHNICAL MEETINGS

2004 National Manufacturing Week

Chicago, Illinois
February 23–26, 2004
http://www.manufacturingweek.com/

National Manufacturing Week brings together six show and conference (SAC) and other events: National Design Engineering SAC, National Plant Engineering and Facilities Management SAC, CleanTech International Cleaning Technology Exposition, National Industrial Automation SAC, National Enterprise IT SAC, and the Technology Transfer Conference and Exposition.

2004 NASA Cell Science Conference

Palo Alto, California
February 26–28, 2004
http://slsd.jsc.nasa.gov/BSO/IWG/

Sponsored by the Cellular Biotechnology Program at Johnson Space Center, Houston, Texas, and the Fundamental Space Biology Program at Ames Research Center, Moffett Field, California, this conference aims to foster coordination and collaboration among the various NASA programs that use cell systems in basic and applied research, in flight and on the ground.

Biotechnology Industry Organization (BIO) 2004 Annual International Convention

San Francisco, California
June 6–9, 2004
http://www.bio.org/events/2004/index.asp

This convention invites executives, investors, scientists, policy leaders, and journalists to discuss the future of biotechnology. It will bring together more than 15,000 biotechnology experts and will include more than 190 sessions, almost 1,000 speakers, and more than 1,200 exhibitors. Topics for speeches include infectious diseases, bioterrorism, business development, and cancer.

EDUCATION MEETINGS

International Technology Education Association's (ITEA's) 66th Annual Conference

Albuquerque, New Mexico
March 18–20, 2004
http://www.iteawww.org/D.html

The conference title is "Teaching Decision Making in a Technological World." Attendees will have the opportunity to gather with other technology educators to share ideas, problems, and solutions and to network during the Technology Festival ("Tech Fest").

37th National Congress on Aviation and Space Education

Atlanta, Georgia
March 24–27, 2004
http://www.cap.gov/events/ncmain.html

This standards-focused educational event is geared toward using hands-on and minds-on classroom activities with aviation and space themes to teach traditional subjects and also inspire students at all levels to explore science, math, and technology in more depth. The theme, "Teaching Today for Tomorrow," reflects a focus on preparing students for careers in the aerospace industry.

52nd National Science Teachers Association (NSTA) National Convention

Atlanta, Georgia
April 1–4, 2004
http://www.nsta.org/conventiondetail&Meeting_Code=2004ATL

Geared toward science teachers, science department heads, and curriculum specialists from elementary school through college, this convention will provide attendees the opportunity to explore the latest ideas and teaching materials. Attendees can pick from hundreds of workshops and presentations, including the new Internet-based Virtual Exhibitor Workshops.

PROGRAM RESOURCES

General site

Office of Biological and Physical Research
http://spaceresearch.nasa.gov

- Latest biological and physical research news
- Research on the International Space Station
- Articles on research activities
- Space commercialization
- Educational resources

Descriptions of funded research projects

Science program projects
http://research.hq.nasa.gov/taskbook.cfm
Commercial projects
(also includes links to a description of the Commercial Space Center Program and other information)
http://spd.nasa.gov/sourcebook/index.html
Space life sciences research resources
(for literature searches)
http://spaceline.usuhs.mil/home/newsearch.html

National Council of Teachers of Mathematics (NCTM) 82nd Annual Meeting

Philadelphia, Pennsylvania
April 21–24, 2004
http://www.nctm.org/meetings/philadelphia/index.htm

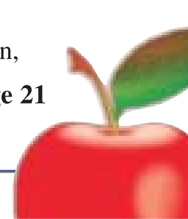
The National Council of Teachers of Mathematics offers its members the chance to gather with others who share their professional interests. Attendees can choose from among 1,000 different sessions to learn new ideas and possible solutions to problems they may have encountered during the past year.

NECC 2004: 25th Annual National Educational Computing Conference

New Orleans, Louisiana
June 21–23, 2004
http://www.neccsite.org/

Presented by the International Society for Technology in Education,

continued on page 21



***Inspire** continued from page 7*

at a new web site called Space Biology: An Educator's Resource (*http://spacebio.net*). The site provides information about the latest questions and findings of microgravity research in the life sciences for incorporation into undergraduate courses. It also offers teaching modules on more than a dozen topics of current microgravity research, including developmental biology, gravity sensing and signal transduction, plant biology, neuroscience, microbiology, and life in the universe. Each module contains an introduction; readings and references; and various downloadable materials such as lecture topics, presentations, lecture notes, still images, video clips, and classroom demonstrations.

Fishing for knowledge

Based at Kennedy Space Center, Cape Canaveral, Florida, NASA's Spaceflight and Life Sciences Training Program (SLSTP) was created specifically "to get underrepresented minorities interested in life sciences and engineering," explains Jan Barfus, curriculum coordinator. Many minorities are underrepresented in these fields, not because of lack of ability but because of lack of exposure.

SLSTP runs for 6 weeks in the summer, during which time the students conduct individual research projects. This solid, hands-on experience helps guide their future career choices and solidify their interests in life sciences and engineering. Students also take what they've learned back to their communities, acting as ambassadors between NASA and the public.

Inspiring the current generation

A program in the aerospace engineering department at the University of Colorado (CU), Boulder, provides a novel approach to preparing undergraduates and graduate students for careers in bioastronautics-related hardware design and microgravity research.

The academic model largely stemmed from CU's connection with BioServe Space Technologies, one of 15 research partnership centers run by NASA through OBPR's Space Product Development Division. BioServe's research program provides the in-house expertise of personnel who support the course offerings at CU as well as hands-on opportunities for students to work on actual spaceflight projects.

BioServe student volunteers and research assistants help design, build, test, and operate payloads that fly on NASA's KC-135 parabolic aircraft, on space shuttles and expendable rockets, and to the International Space Station (ISS). The students are involved in all stages of payload activity, from prelaunch development to postflight analysis.

Back to school for teachers

To transfer the excitement of space reasearch to students, one OBPR program is transferring it first to teachers. NASA's National Space and Biomedical Research Institute (NSBRI) runs the Teacher Academy Program (TAP), which teaches educators the latest in microgravity research to use in their science curricula. Begun more than 6 years ago, TAP trains 20–30 middle school science teachers annually. The teachers attend classes taught by NSBRI scientists and educators at Texas A&M University (College Station) for 10 days during the summer and tour Johnson Space Center, Houston, Texas, for 2 days.

After teachers are trained, they return to their home states and start training other teachers. The teachers who have passed certain requirements become certified as TAP fellows. As of last year, a total of 50 fellows had trained more than 2,500 additional teachers.

Bonnie McClain

For more information about the Office of Biological and Physical Research's Educational Outreach Program, see *http://spaceresearch.nasa.gov/fun_learning/edu.html*. For a schedule of NASA CONNECT airings or information about how to receive a videotape of the Better Health from Space to Earth program, visit *http://connect.larc.nasa.gov/*. The teacher's guide and related web activity are also available. Science in a Box instructions and guide are available at *http://www.ncmr.org/education/k12/in_a_box.html*. For more information about the SLSTP program, visit *http://slstp.nasa.gov/*.
For more information about BioServe's Academic Program, visit *http://www.colorado.edu/engineering/BioServe/*.
For more information about the Teacher Academy Program, visit *http://www.nsbri.org/Education/2001-2003/JamesAbstract.html*.

***Bacterium's Virulence** continued from page 11*

bacteria than in the control group). In this way, Niesel will be able to observe exactly which of *S. pneumoniae's* genes are exclusively overexpressed (or upregulated) during exposure to microgravity. He anticipates that genes representing all these possibilities will be identified. Analysis of these gene expression patterns will begin to describe how this bacterium responds in this unique environment.

Single cells, multiple answers

As in most organisms with completely mapped genomes, the functions of some of the genes of *S. pneumoniae* are not known. "But the common prejudice," Niesel says, "is that they are probably genes that the bacterium uses to respond to different unique conditions." In other words, chances are good that Niesel may run into some of these genes in his research in microgravity (modeled and actual). "We may find genes, whose function we don't know, that may be turned on or off under microgravity conditions," he explains, "and so we'll start to describe the properties of those genes in a functional way." Niesel adds, "Many people think that some of the genes whose functions are currently not known will be some that contribute to the bacterium's ability to cause disease."

In addition to identifying changes in gene regulation and exploring the unknown functions of some genes, Niesel hopes to gain a better understanding of the pathogenic mechanisms of the bacterium and give researchers more options for controlling those diseases, especially as antibiotic-resistant strains of the bacteria are constantly emerging: "So there's a fundamental aspect to the research and a biomedical aspect, too."

Niesel's research also offers another potential benefit. Ultimately, it should allow for a more realistic assessment of the risk posed by opportunistic pathogens during extended space missions and provide methods for mitigating that risk so astronauts can stay healthy as they and their microbe passengers explore the cosmos together.

Julie K. Poudrier

For more information about Niesel's research, visit *http://microbiology.utmb.edu/faculty/niesel/homepage.htm#RESEARCH INTERESTS*. For a FLASH animation of DNA microarray technology, see *http://www.bio.Davidson.edu/courses/genomics/chip/chip.html*. For information about the Pathogen Functional Genomics Resource Center see *http://pfgrc.tigr.org/*.

Pumping Iron *continued from page 9*

precisely characterize variations in muscle fiber size, peak force, power, speed, and tear resistance.

On Mars and Earth

Fitts will use the data obtained from his experiments on single muscle fibers to try to predict changes that may occur in muscles during such prolonged space missions as a voyage to Mars. His measurements will also provide important baseline data for evaluating future microgravity exercise programs.

Some of Fitts' discoveries may have an immediate impact on Earth. People steadily lose muscle mass and aerobic power after age 55. Until recently, physiologists have typically recommended aerobic exercise to counter this effect. "The problem with walking or bicycling is that many elderly are too weak to get out of a chair," says Fitts. "Until very recently, most fitness programs for the elderly didn't emphasize muscle mass. Therapists are just starting to get the word that the elderly need resistance exercises, too."

The challenge, says Fitts, is choosing the right exercises. That's where space research comes in. "Spaceflight acts like accelerated aging," he explains. "It causes rapid loss of muscle mass. If we can learn how to prevent muscles from wasting during spaceflight, that information can help people on Earth stay strong as they age." The same insights could help patients with serious burns, who are often confined to bed for months and treated with steroids that break down muscle. "Optimal exercise could reduce rehabilitation time in many clinical settings," Fitts explains.

By honing today's best approaches in the demanding microgravity environment, NASA researchers may learn how to keep muscles strong and healthy in microgravity as well as on Earth.

Alan S. Brown

Robert H. Fitts' research team includes Scott Trappe and Dave Costill of Ball State University (Muncie, Indiana) and Danny Riley of Medical College of Wisconsin in Milwaukee. For more information about Fitts' research, visit *http://research.hq.nasa.gov/taskbook/tb2002/search/retrieve_task.cfm?task_id=1287*, *http://spaceresearch.nasa.gov/research_projects/ros/biopsyresults.html*, and *http://mendel. biol.mu.edu/fitts*. Details of the group's research have been published in "Physiology of a microgravity environment" (R. H. Fitts, D. R. Riley, and J. J. Widrick, Invited Review: Microgravity and skeletal muscle, *Journal of Applied Physiology, 89*, 823–839, 2000).

Robotic Rover *continued from page 15*

Moon dust supports a field of opportunities

Even if the conceptual Moon rover becomes a reality tomorrow, no missions are currently planned to Earth's nearest neighbor. The TcSAM work on the project opens the door to providing this type of technology for missions to other planets or moons with stable atmospheres, such as Europa, says Freundlich.

Having solar panels on the Moon could pay its own dividends. They could power a lunar research station; Freundlich and Ignatiev agree that there's still much to learn about the composition and structure of the lunar environment. The Moon would make a good site from which to investigate the rest of the cosmos because it would serve as a place from which to launch rockets. To further their exploration of the universe, astronomers could erect a radio telescope on the back side of the Moon, where there would be no radio interference from Earth. Lunar solar cells could eventually power a commercial mining operation. And the panels might even beam electricity back to Earth.

"People have a desire to explore beyond the International Space Station. I think colonizing the Moon and working out these technologies is just as important as going to Mars," says Freundlich. "Going to Mars as a first step is like climbing to the top of the Himalayas when you've never been to the top of a 4,000-foot [1,219.2-meter] mountain. No one will climb Mount Everest without [first] establishing a base and training at lower altitudes."

Jeanne Erdmann

To learn more about work with solar panels at the Texas Center for Superconductivity of Advanced Materials, visit the center's web site at *http://www.svec.uh.edu/* (click on Photovoltaics and Nanostructures). For moon facts, visit *http://nssdc.gsfc.nasa.gov/planetary/planets/moonpage.html.* To learn about lunar soil, visit *http://www-curator.jsc.nasa.gov/curator/lunar/lunar.htm.*

Meetings *continued from page 19*

this conference title is "Jammin' & Jazzin' with Technology." More than 16,000 teachers, technology coordinators, library media specialists, teacher educators, administrators, policy makers, and industry representatives from the world over will gather to share ideas and promote education through technology.

RESEARCH OPPORTUNITIES

http://research.hq.nasa.gov/code_u/code_u.cfm

Research opportunities in physical sciences

Information about fiscal 2003 NASA Research Announcements (NRAs) for the Physical Sciences Research (PSR) Division, NRA-02-OBPR-03, can be found at *http://research.hq.nasa.gov/code_u/open.cfm.*

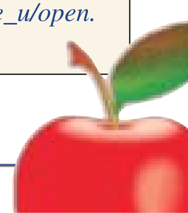
In addition, selections are still being made for NRA-01-OBPR-08, the PSR Division's NRA for 2002. For more information about this announcement, see *http://research.hq.nasa.gov/code_u/nra/current/NRA-01-OBPR-08/index.html.*

Research grants funded for fundamental physics

OBPR has selected 15 researchers to receive grants totaling more than $6.4 million over 4 years. Selected through NRA-02-OBPR-03-D, these awards support ground-based fundamental physics research. The list of grantees is posted at *http://www.nasa.gov/home/hqnews/2003/oct/funphys_award_ list.html*.

Solicitation released for space radiation biology and shielding materials

Proposals were due on January 9, 2004, for NRA-03-OBPR-07 soliciting projects for ground-based research in space radiation biology and materials that shield against space radiation. Research will be conducted at the NASA Space Radiation Laboratory (NSRL) at Brookhaven National Laboratory, Upton, New York. For more information, see *http://research.hq.nasa.gov/code_u/open.cfm/*.



Freezing *continued from page 13*

where dirt or irregularities would act as nucleation sites for crystals. Not until 1997, when NASA's Electrostatic Levitator at Marshall Space Flight Center in Huntsville, Alabama, began operation, could scientists readily study the undercooling of an electrostatically levitated drop of molten metal.

With the availability of these high-tech tools, Kelton's team combined the two capabilities needed for the measurements by moving NASA's Electrostatic Levitator to the Advanced Photon Source (APS), a source of high-intensity X-rays at Argonne National Laboratory in Argonne, Illinois. In May 2003, Kelton and his group announced that they had tested and verified Frank's hypothesis, presenting the first observational data directly linking the nucleation of metal crystals with the icosahedral order of atoms in undercooled liquid metals.

Kelton's tricky levitation magic

To measure the positions of individual atoms inside a droplet of titanium–zirconium–nickel, Kelton first placed a sphere of the solid alloy (2.5 millimeters [0.1 inch] in diameter) into the vacuum chamber of the APS. Then, he shined ultraviolet light on the sphere to put a positive electric charge on it, so it could be suspended in the electrostatic field of the Electrostatic Levitator. With a laser, Kelton heated the floating sphere to high above its melting temperature of 1,093K (1,508°F). Next, he probed the hovering droplet with an energetic beam of X-rays that was diffracted in a pattern representing the locations of the droplet's atoms. Then, a high-speed detector measured the changing diffraction patterns as the droplet cooled. Finally, Kelton just watched.

Repeatedly, Kelton observed that the droplet remained liquid as it cooled to well below the temperature at which it was expected to begin solidifying (1,083K [1,490°F]), all the way to 953K (1,256°F). Then, the droplet's temperature shot up to 1,058K (1,445°F). As the sample was cooled below the melting temperature before the temperature jump, however, the X-ray diffraction pattern of the liquid changed, indicating the development of local icosahedral order. It changed again as the temperature shot up, showing the development of the sharp diffraction peaks characteristic of a solid icosahedral quasicrystal. A few seconds later, the temperature of the sample (whether it was completely solidified or still contained a small amount of liquid is still not certain) rose more gradually back up to 1,083K (the temperature at which the alloy was expected to begin solidifying); simultaneously, the diffraction pattern changed yet again, this time to the peaks expected for its equilibrium hexagonal crystal phase. At that point, the temperature resumed dropping steadily as the metal completely crystallized.

In this repeatable sequence of events, Kelton realized that he was witnessing the atoms in the undercooled liquid metal shuffle into an icosahedral order before the temperature jump. Immediately afterward, solid icosahedral quasicrystals nucleated and grew, releasing the heat of fusion and raising the temperature of the liquid. That surprised Kelton. The crystal phase was the thermodynamically stable phase, so Kelton reasoned it should have been the first one to form. That it didn't could only be explained by the quasicrystal's having a lower nucleation barrier, possibly because the local arrangement of atoms in the quasicrystal was more similar to that in the liquid. Because the quasicrystals were less stable than the crystal phase, the atoms finally settled into the solid alloy's expected crystalline structure before cooling completely. Thus, Kelton proved that a local icosahedral order in undercooled liquid metals is directly linked to an energy barrier that causes the molten metals to resist solidification to crystal phases — just as Frank had hypothesized half a century earlier.

Droplets in orbit

Kelton is eager to conduct related nucleation studies of undercooled liquids aboard the International Space Station (one of his experiments has been approved for launch sometime this decade). In microgravity, a molten sample can float without the use of electrostatic fields, thus allowing the investigation of larger amounts of the alloy that Kelton has been testing on Earth. Even more importantly, Kelton will be able to measure other properties of a solidifying droplet that are not measurable under electrostatic or electromagnetic levitation, such as the droplet's electrical resistivity — a measurement critical to investigating a wholly new type of phase transition that he believes he has discovered in the undercooled liquid alloy. Microgravity also will allow him to observe the importance of atomic diffusion (the movement of atoms) for nucleation in the molten droplet in the absence of gravity-driven stirring (convection). Because he will simultaneously be able to measure other physical parameters (such as the heat of fusion and the specific heats of the liquid and solid phases), he plans to make benchmark measurements of the nucleation rate and compare his observed results with the predictions of nucleation theories.

The stakes are high.

"There's a widespread belief that parts of the classical theory of nucleation are flawed," Kelton explains. Going into space will allow him and his colleagues "to poke at [the basic physics] of nucleation." Nucleation and crystallization are key to many natural and industrial processes, so understanding the basic physics behind these processes could alter underlying theories of what happens during crystallization and allow the creation of novel materials for advanced applications.

The payoff for NASA and Earth? Kelton's research on fundamental nucleation processes in liquids could lead to better control of the microstructural development of materials. In the absence of gravity, nucleation will be controlled by atomic diffusion, a feature not considered in the commonly used theories and models on Earth but that could be key to in-flight materials processing and fabrication methods, considered to be essential for long-duration flights beyond Earth orbit. Additionally, the quasicrystals that he studies are important in their own right, as potential new materials for such advanced applications as nonstick, corrosion-resistant coatings and hydrogen storage.

Trudy E. Bell

Kelton's research team includes Geun Woo Lee and Anup Gangopadhyay of Washington University (St. Louis, Missouri); Jan Rogers, Tom Rathz, and Mike Robinson of Marshall Space Flight Center (Huntsville, Alabama); Robert Hyers of the University of Massachusetts, Amherst; and Doug Robinson of the U.S. Department of Energy's Ames Laboratory (Ames, Iowa).

For more information about Kelton's experiment, see the press release "NASA experiments validate 50-year-old hypothesis" at *http://www1.msfc.nasa.gov/NEWSROOM/news/releases/2003/03-104.html*. For background about NASA's Electrostatic Levitator and the basics of undercooling, see "Look Ma — no hands!" at *http://science.nasa.gov/headlines/y2001/ast23apr_1.htm*. A general background article about Kelton's studies is "Experiments vindicate a 50-year-old explanation of how liquid metals resist solidification" by Charles Day (*Physics Today, 56*, 24–26, July 2003; *http://www.physicstoday.org/vol-56/iss-7/p24.html*).

Profile: Roger Crouch

The same destination can be reached by several different roads, and sometimes the path taken may be an unplanned one. Such was the case for Roger Crouch, whose path led him to NASA and into low Earth orbit before he reached the classroom.

If you ask Roger Crouch what important detail about his life doesn't appear in his official astronaut biography, he will tell you it's that both his parents were educators and that he always wanted to follow in their footsteps. Crouch, who received his doctorate in physics in 1971 from Virginia Polytechnic Institute and State University in Blacksburg, describes his career path this way: "You know how fate does these things — you have plans for what you want your life to be like, [but] it always seems that, at least in my life, I've never followed the road that I laid out. But I wound up in places I never dreamed I'd be able to get to."

credit: NASA

Physicist and former astronaut Roger Crouch poses with students at the opening of the NASA @ your library exhibit (see page 16 in this issue) at the Enoch Pratt Free Library in Baltimore, Maryland.

Crouch recalls that 1971 "was a time when a lot of physicists ended up working in service stations because there weren't a lot of jobs for scientists. I had gotten a good job at Langley [NASA Langley Research Center, Hampton, Virginia] after getting my undergraduate degree, so I was lucky enough to be forced into staying there." And so Crouch began a career in materials science research at NASA that ultimately spanned more than three decades. In 1996, he was selected as a payload specialist because of his background in gravitational effects in materials science, and in 1997 he flew on two space shuttle missions, STS-83 in April and STS-94 in July.

Despite his long detours into research and spaceflight, Crouch says he always had in the back of his mind that he would wind up in the front of a classroom. "I think teaching is probably the most influential job in the world," he remarks. "I don't think I've ever met a person who couldn't recall a great teacher they had who made their life better. I have always wanted to make a contribution to the world through my work. It would be nice to be remembered that way." Happily, he's found that his status as an astronaut "opens an audience up to listen to you more so than if you didn't have that perspective or that credential. As a result, I get a lot of invitations to talk to students and teachers" as well as opportunities to craft or carry a message from NASA to scientists or to the general public.

To Crouch, the key message is how NASA's future is tied to the International Space Station (ISS). "A lot of people berate the space station as something that's useless, saying that we really ought to have a mission of going back to the Moon and then on to Mars," he notes. "They don't realize there's a big abyss we'd be falling into if we don't do research [about long-duration spaceflight] on the space station" before undertaking more dramatic missions. Whether he's talking to schoolchildren, teachers, or other scientists, Crouch's message is that the ISS is vital as a test bed for engineering technology and as a new research tool for scientists before any human journey beyond low Earth orbit.

Crouch often finds himself talking to fourth- through seventh-grade students, encouraging them to learn all they can about whatever subjects interest them the most because "NASA needs all of those things." He says these young people energize him because of their enthusiasm and optimism about the future. "They are so self-confident about their own lives," he says. "They understand there are risky things in the world, and they believe that if they're doing something that's worth doing, then it's worth the risk. It's a real charge for my batteries to get to talk to them."

When Crouch is not talking to children and teachers, he is attending scientific conferences to find the "gems of research that we're funding" and research that "would have applications in the NASA scientific community." He also helps to educate the public as well as his colleagues whenever he can have an impact. For example, he can be found attending NASA @ your library openings (see page 16 in this issue), reaching out to the science community, or helping other NASA employees with education and outreach projects. To all these projects, he brings enthusiasm and down-home charm as well as his conviction that research done under the auspices of the Office of Biological and Physical Research will make a substantive change in the quality of life for people on Earth.

Crouch concludes, "I feel very lucky to be part of shaping NASA's future by helping to inspire the next generation of explorers." And that's exactly the contribution he wants to be remembered for.

Julie K. Poudrier

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